A determination of the global cloud feedback from climate variations over the last decade

A. E. Dessler
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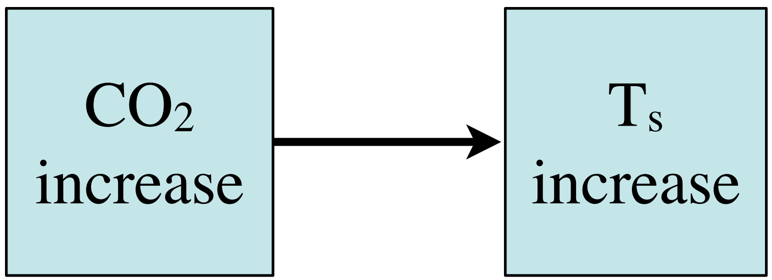
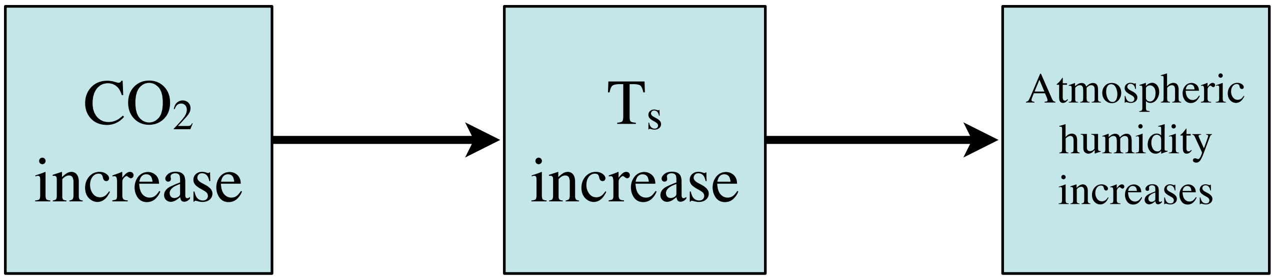
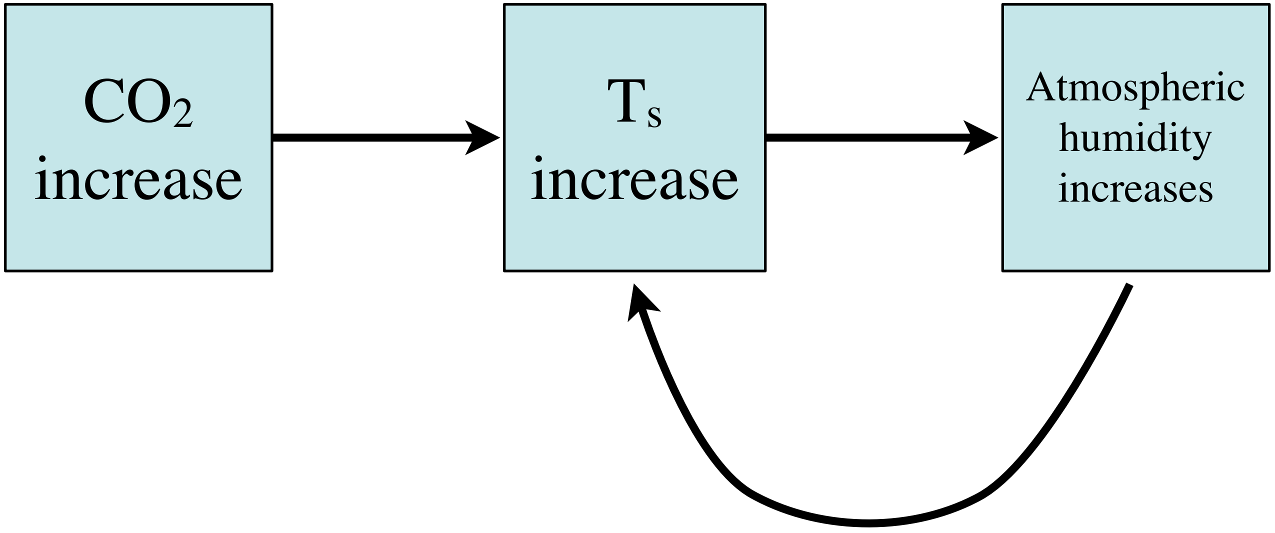

CO_2 increase
T_s increase


CO_2 increase
T_s increase
Atmospheric humidity increases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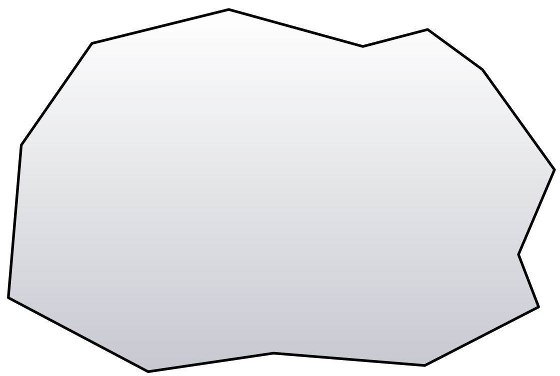
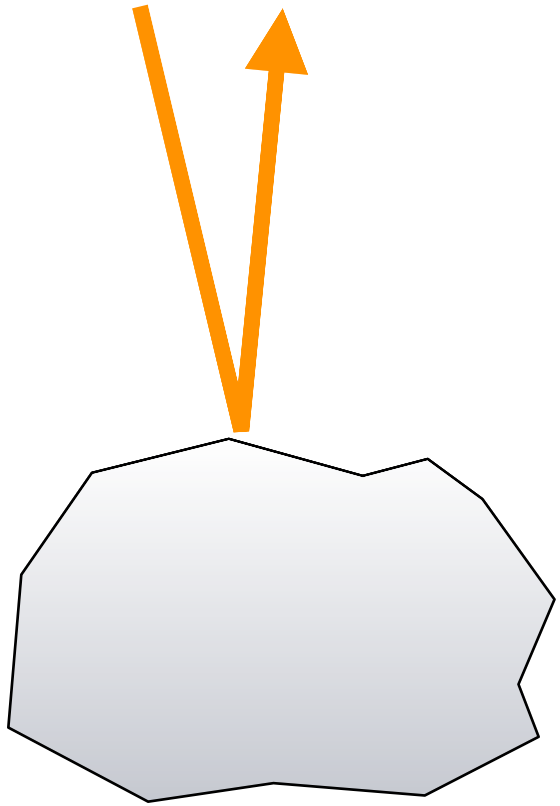


Effect of clouds on the Earth's climate

1) reflect incoming solar: cool
2) reduce outgoing IR: warm

net effect is the difference between these effects



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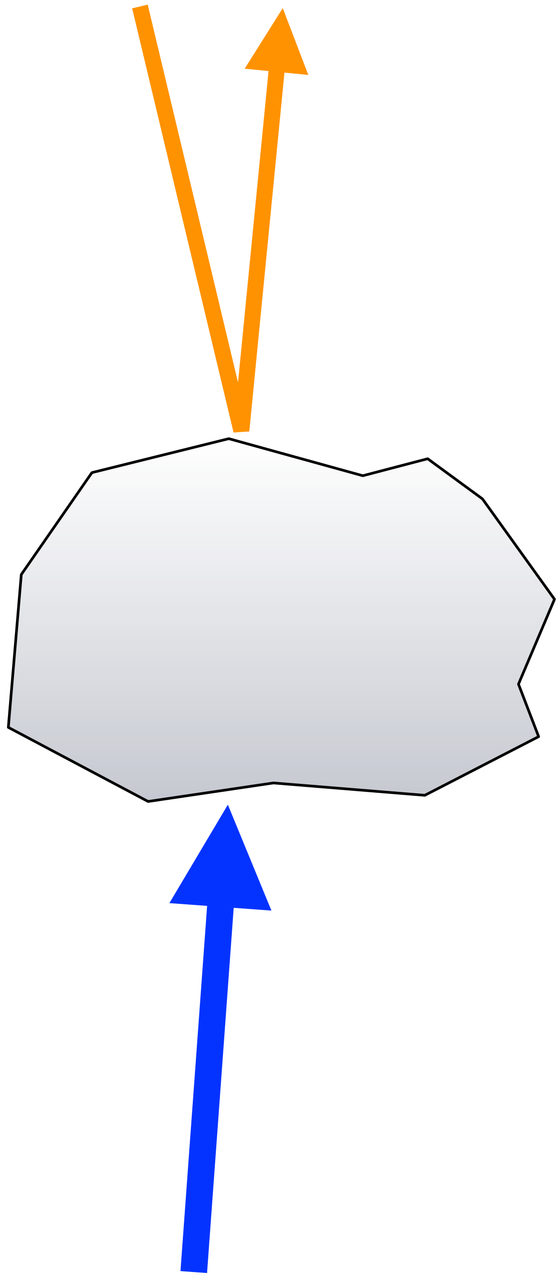

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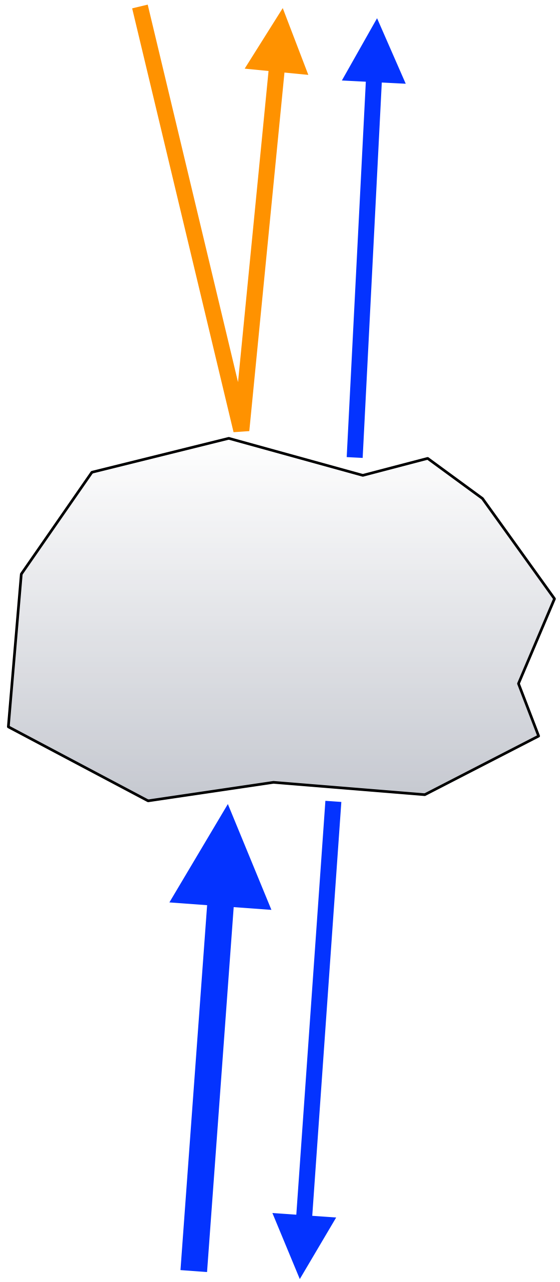

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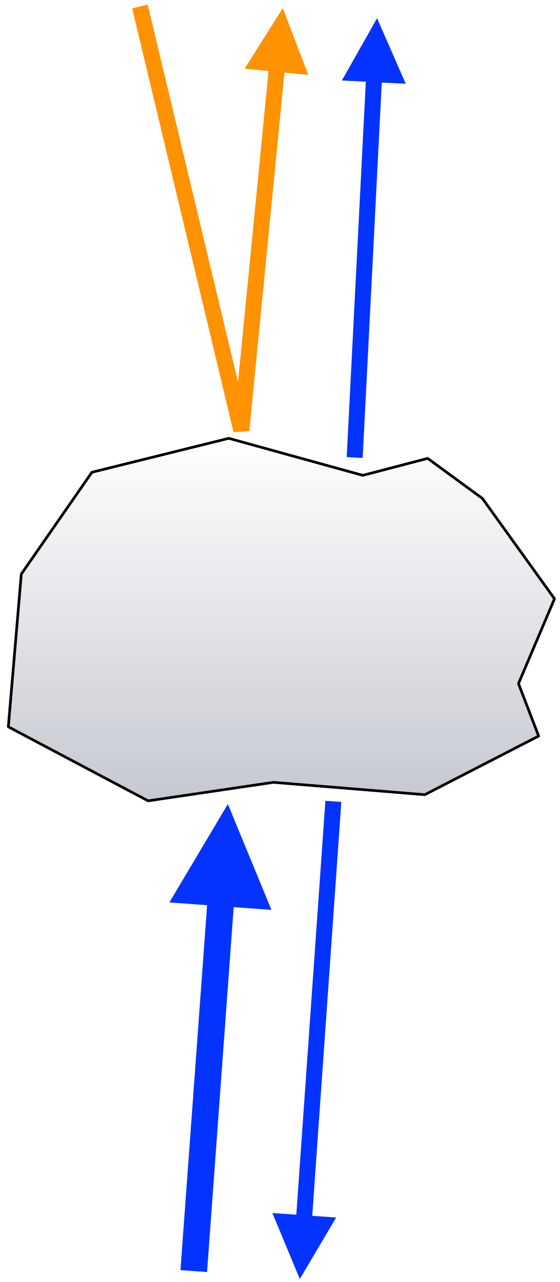


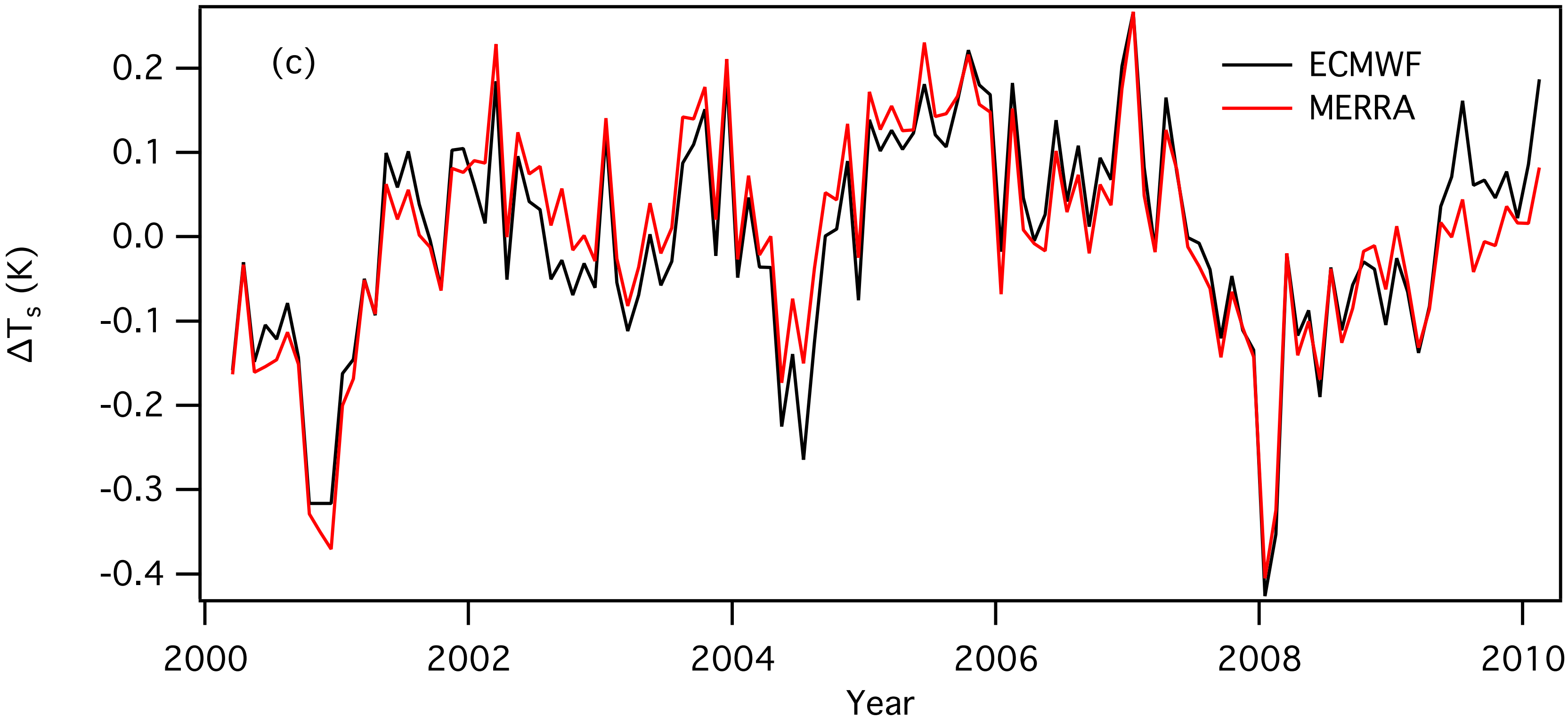
in today's atmosphere, clouds reduce net energy in to the Earth by 20 W/m^2 (also known as cloud radiative forcing)

how will this change in a future climate?

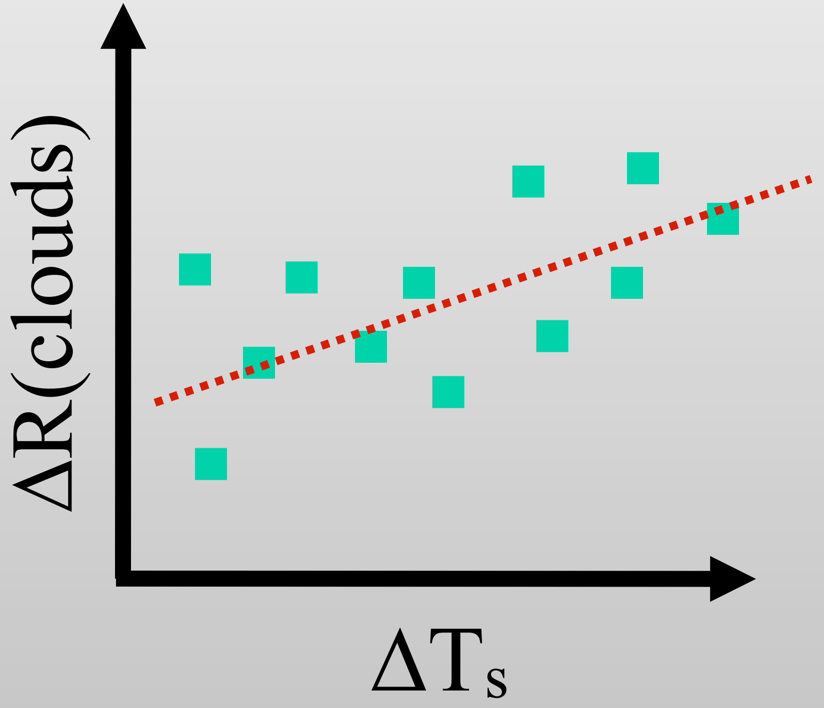
if changing clouds further reduce TOA downward net flux, this is a negative feedback

if changing clouds increase TOA downward net flux, this is a positive feedback

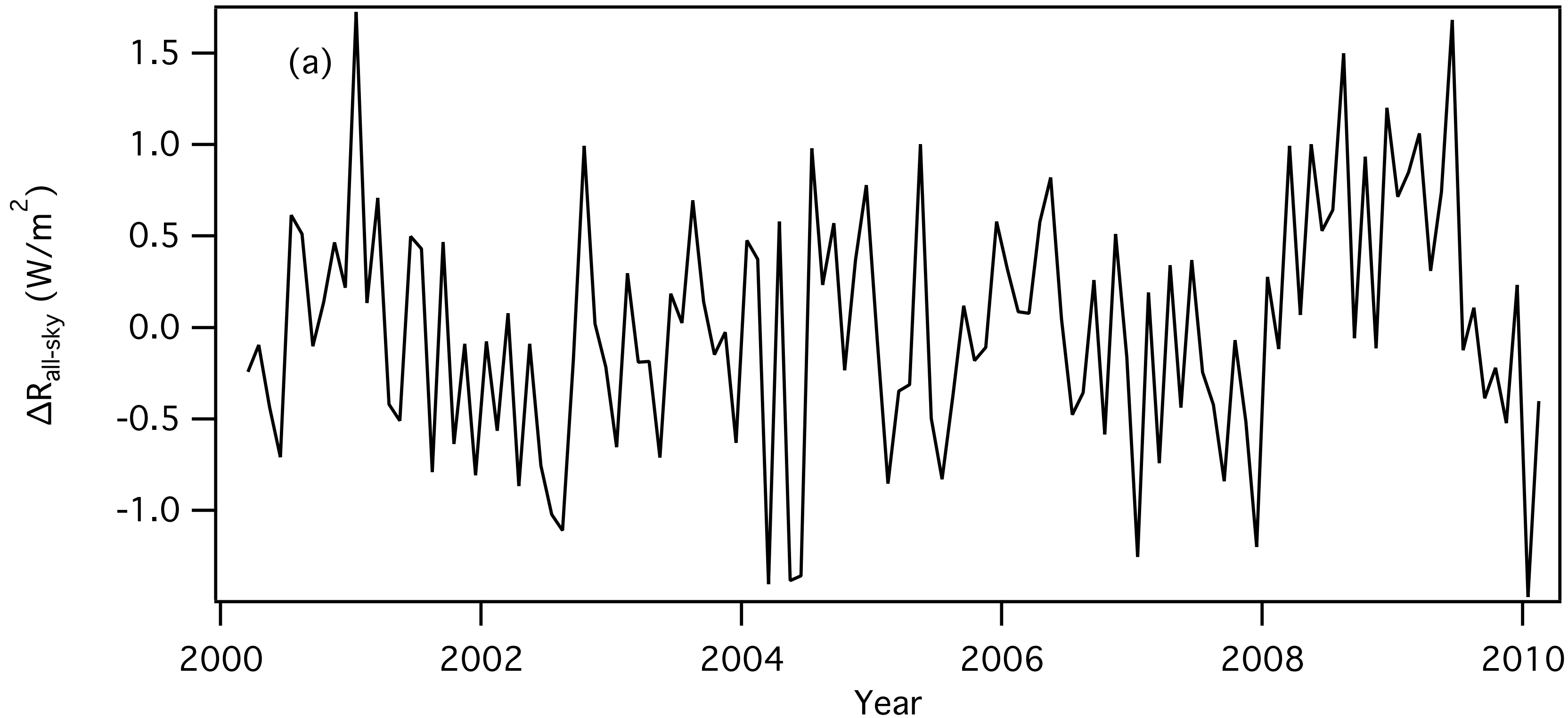
Global average surface temperature anomaly from MERRA and ECMWF-interim



Regress energy trapped by clouds vs. surface temperature

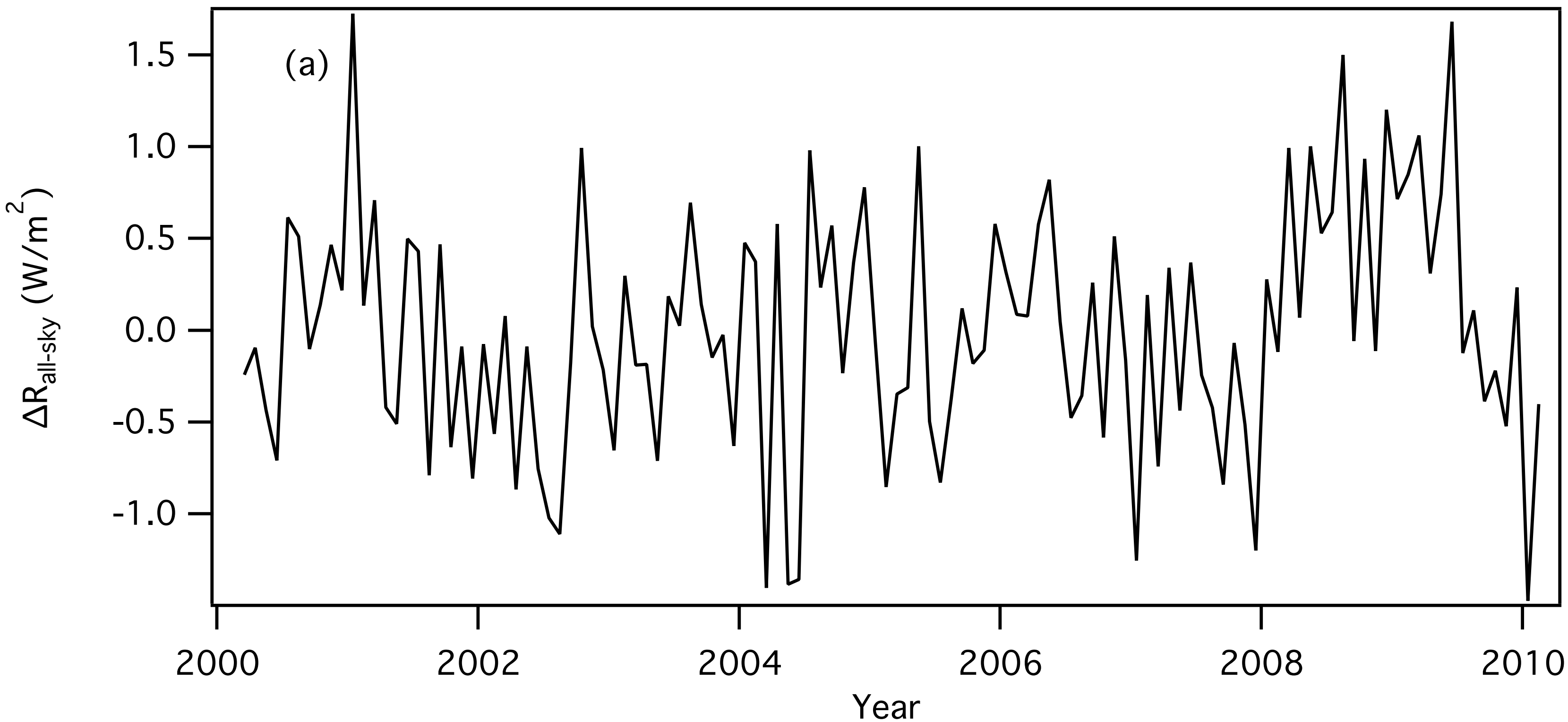


CERES top-of-atmosphere (TOA) net flux
SSF, 1-deg monthly avg., Ed. 2.5



all fluxes in this analysis are downward positive

$$\Delta R_{\text{all-sky}} = \Delta R_T + \Delta R_q + \Delta R_{\text{albedo}} + \Delta R_{\text{cloud}}$$



1. Extract the change that is due just to clouds, ΔR_{cloud}

2. Calculate $$\lambda_{cloud} = \frac{\Delta R_{cloud}}{\Delta T_s}$$

to determine ΔR_{cloud}

- start with cloud radiative forcing (ΔCRF); change in TOA flux if clouds are removed
- $\Delta CRF = (\Delta R_{clear\text{-}sky} - \Delta R_{all\text{-}sky})$
- ΔCRF can also be affected by changes in T, q, albedo, radiative forcing
- Soden et al. [2008] adjustment to get ΔR_{cloud} from ΔCRF; see also Shell et al. [2008]

$$\Delta R_{cloud} = \Delta CRF + (K^0{}_T - K_T)dT + (K^0{}_W - K_W)dW$$

$$+ (K^0{}_a - K_a)da + (G^0 - G).$$

$$\Delta R_{cloud} = \left(\Delta R_{clear-sky} - \Delta R_{all-sky}\right) + (K^0{}_T - K_T)dT + (K^0{}_W - K_W)dW + (K^0{}_a - K_a)da + (G^0 - G).$$

cloud radiative forcing

$$\Delta R_{cloud} = \left(\Delta R_{clear-sky} - \Delta R_{all-sky}\right) + (K^0{}_T - K_T)dT + (K^0{}_W - K_W)dW$$
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adjustment terms

$$\Delta R_{cloud} = \left(\Delta R_{clear-sky} - \Delta R_{all-sky}\right) + (K^0{}_T - K_T)dT + (K^0{}_W - K_W)dW$$
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CERES

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CERES

ECMWF
or
MERRA

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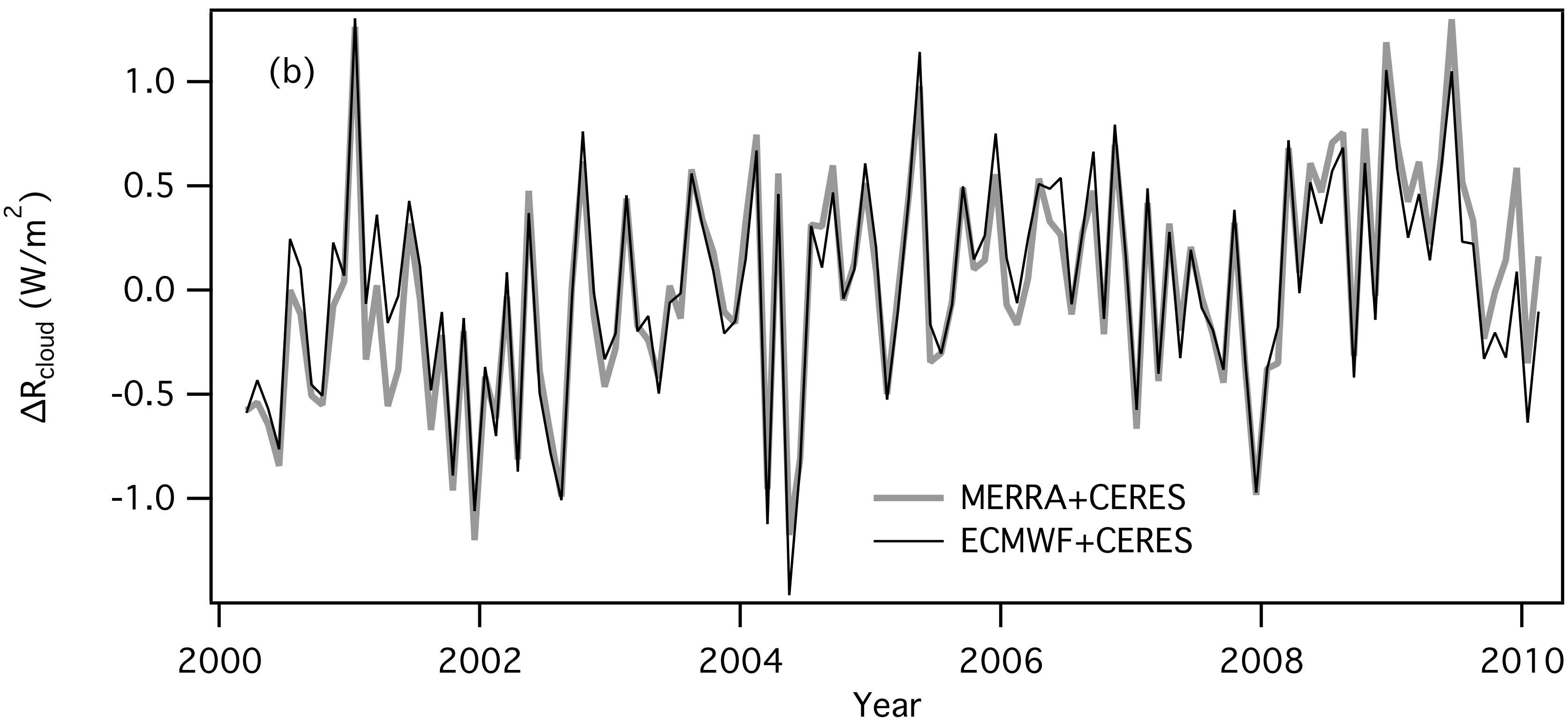
Soden et al.

ΔR_{cloud}



$$\lambda_{cloud} = \frac{\Delta R_{cloud}}{\Delta T_s}$$

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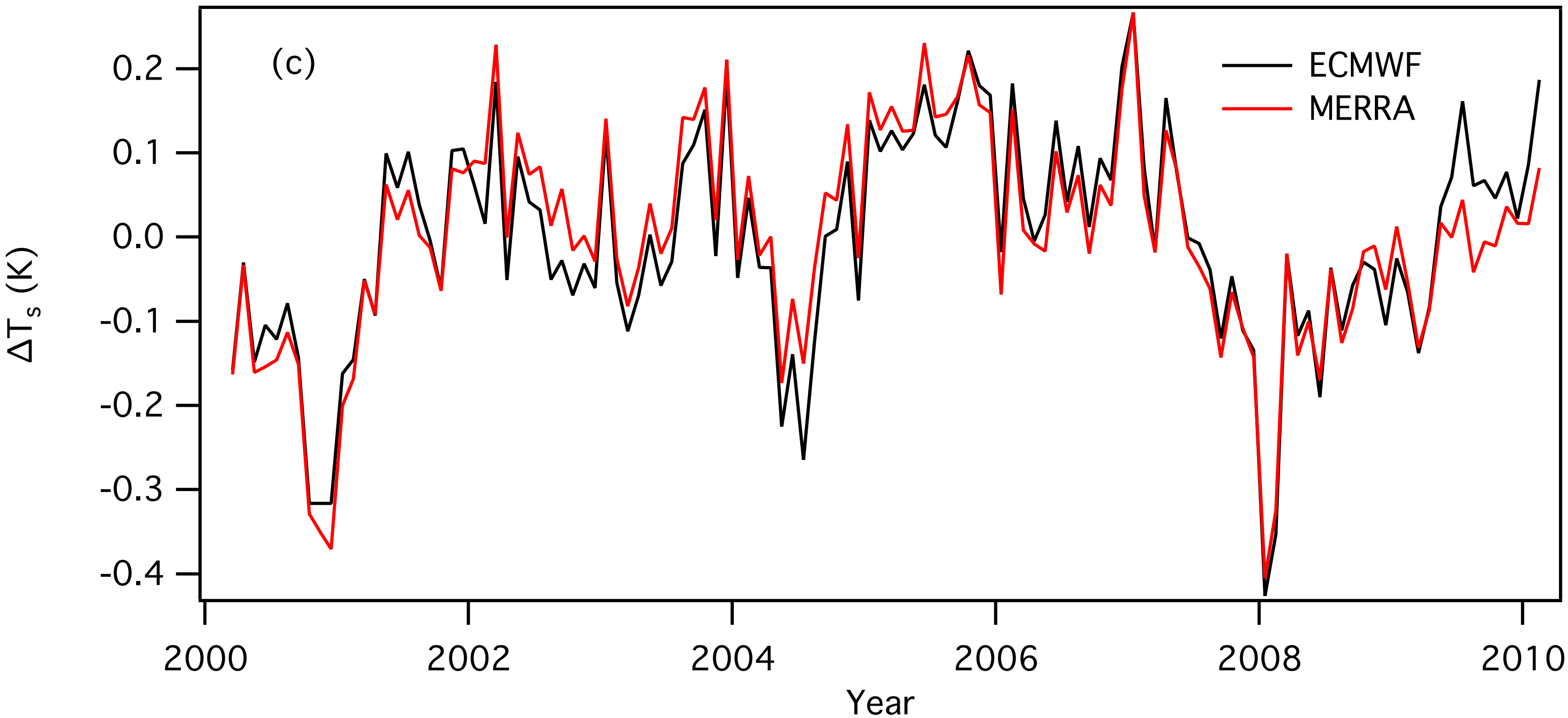

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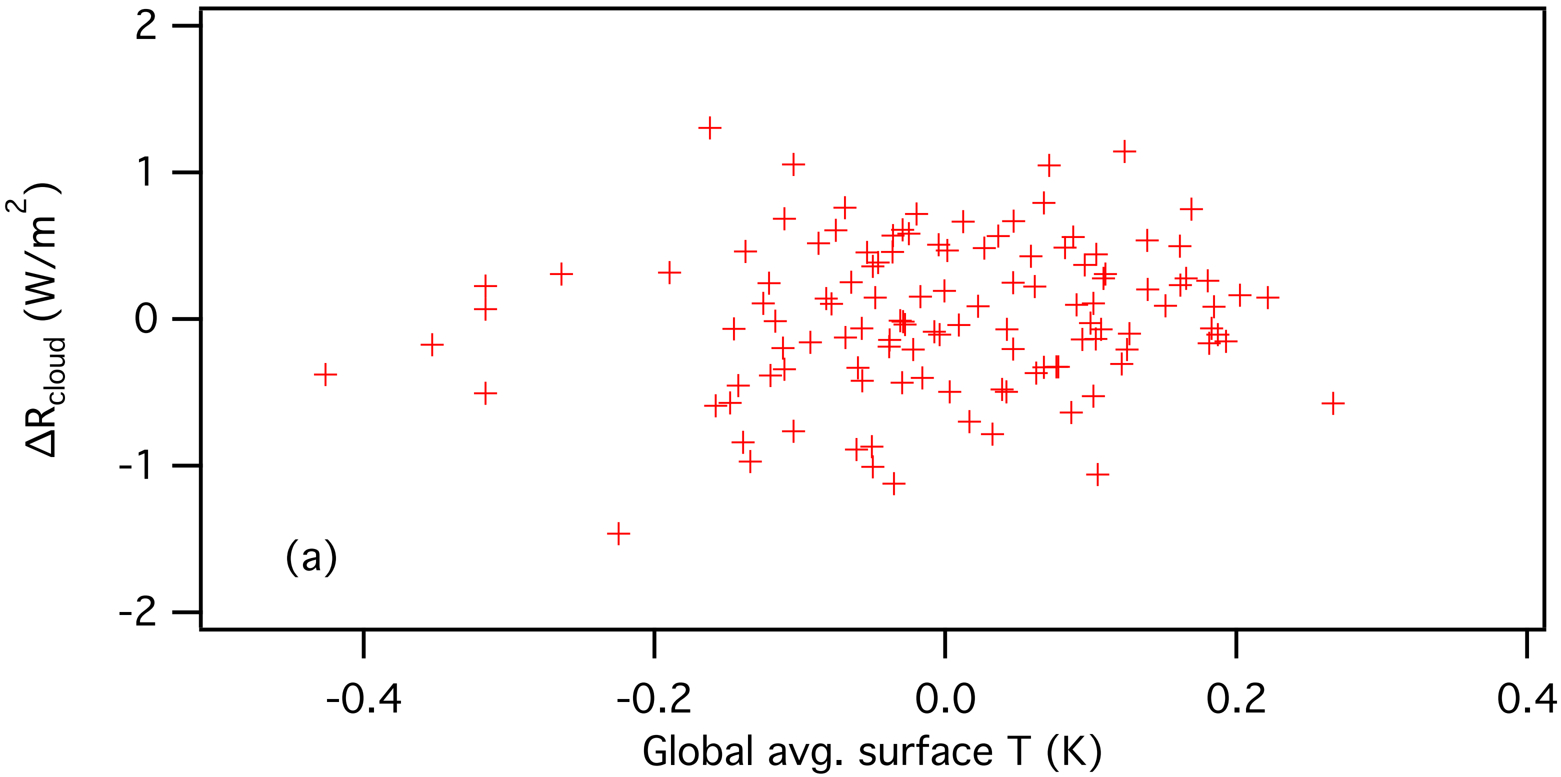
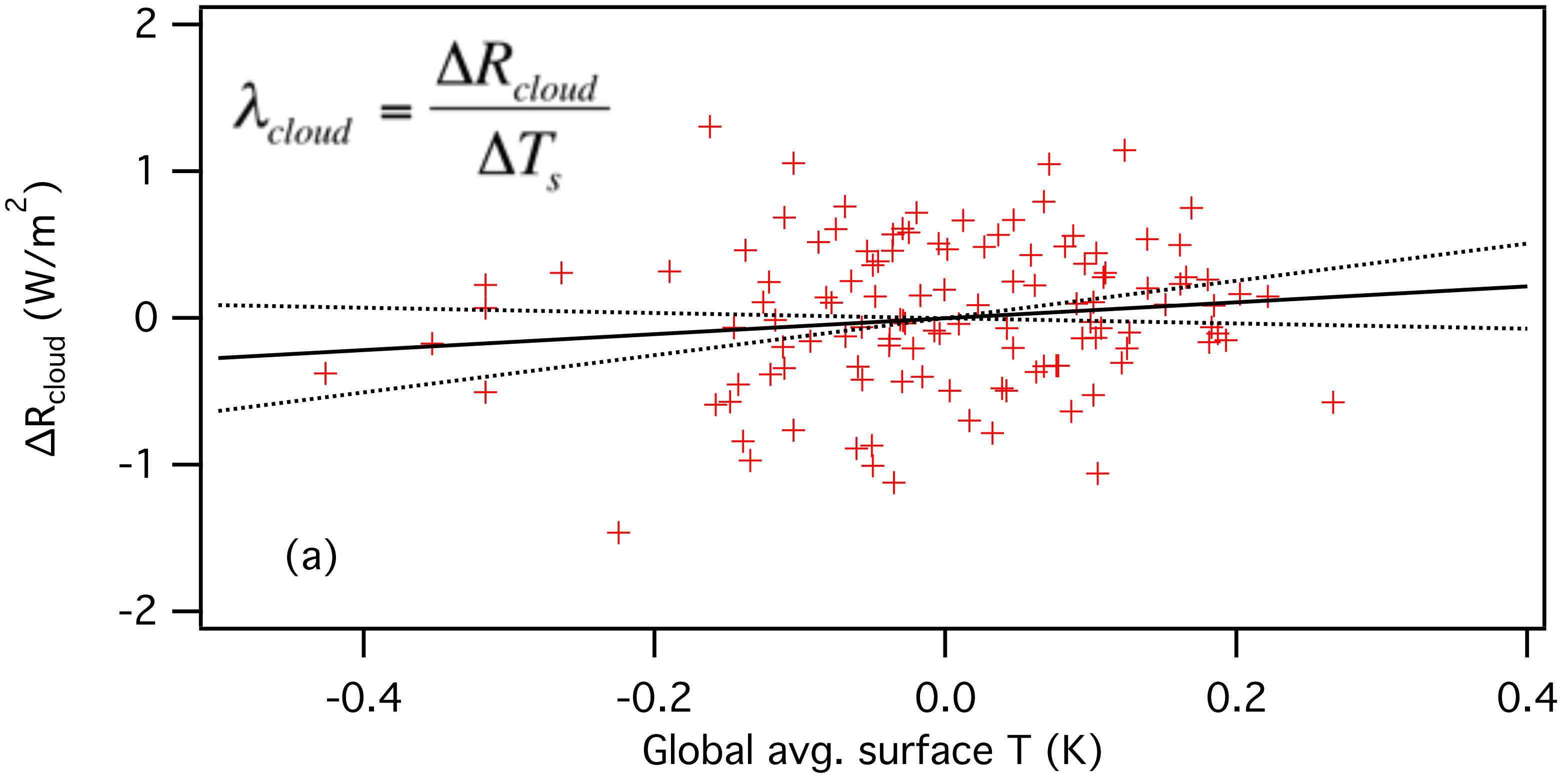


using ECMWF-interim

λ_{cloud} = 0.54±0.72 (2σ) W/m²/K (ECMWF)

= 0.46±0.75 (2σ) W/m²/K (MERRA)



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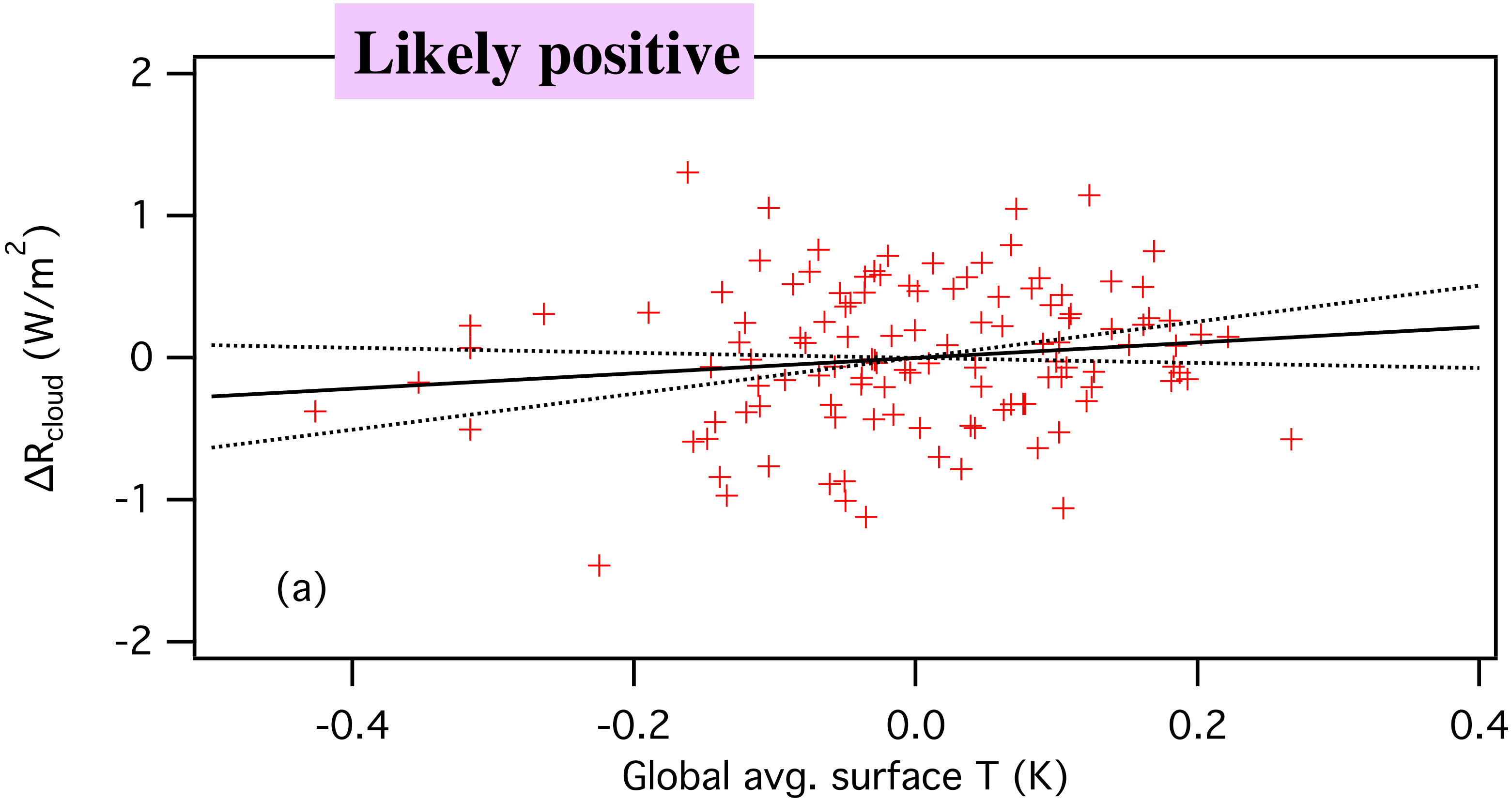

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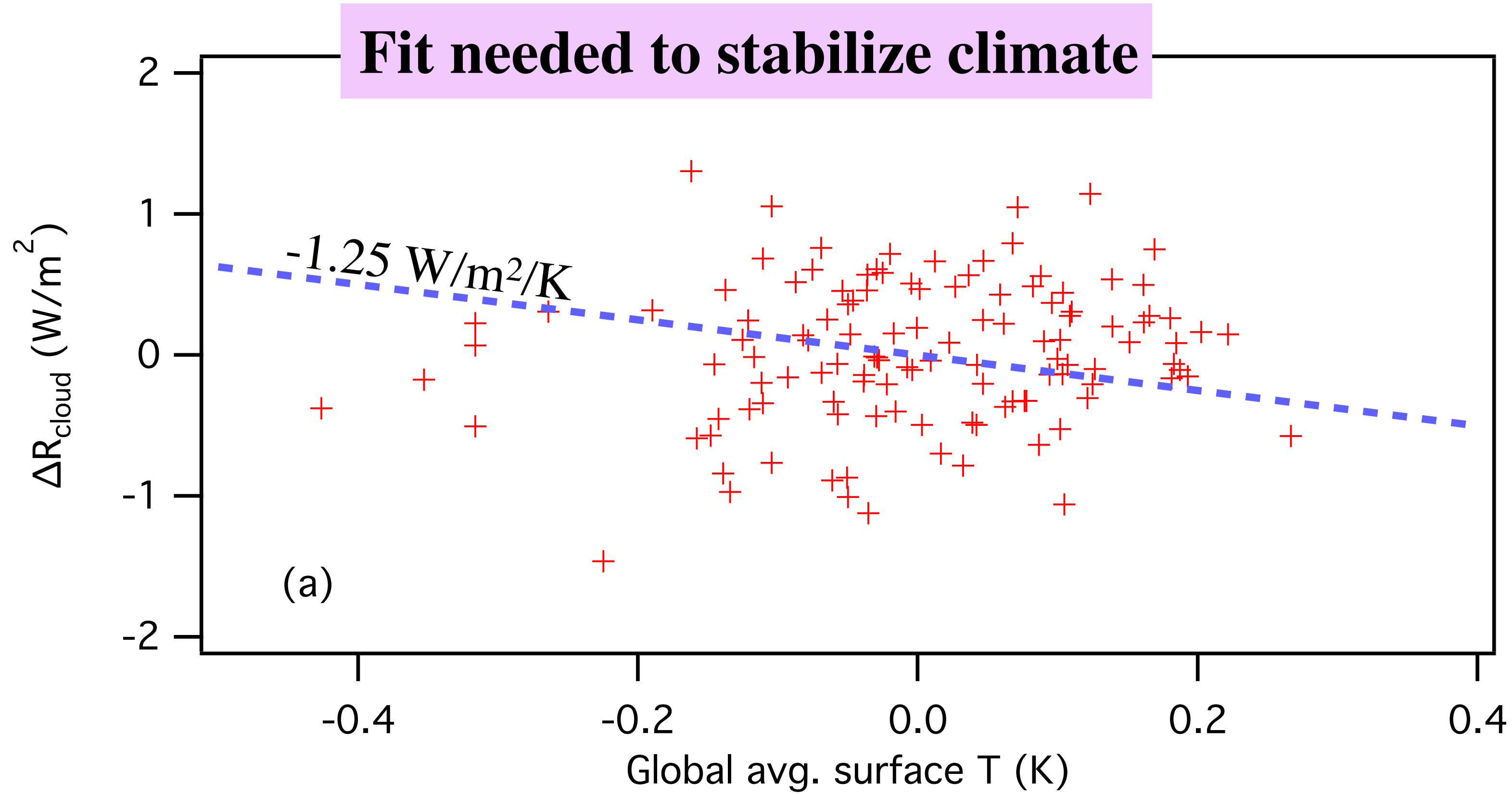
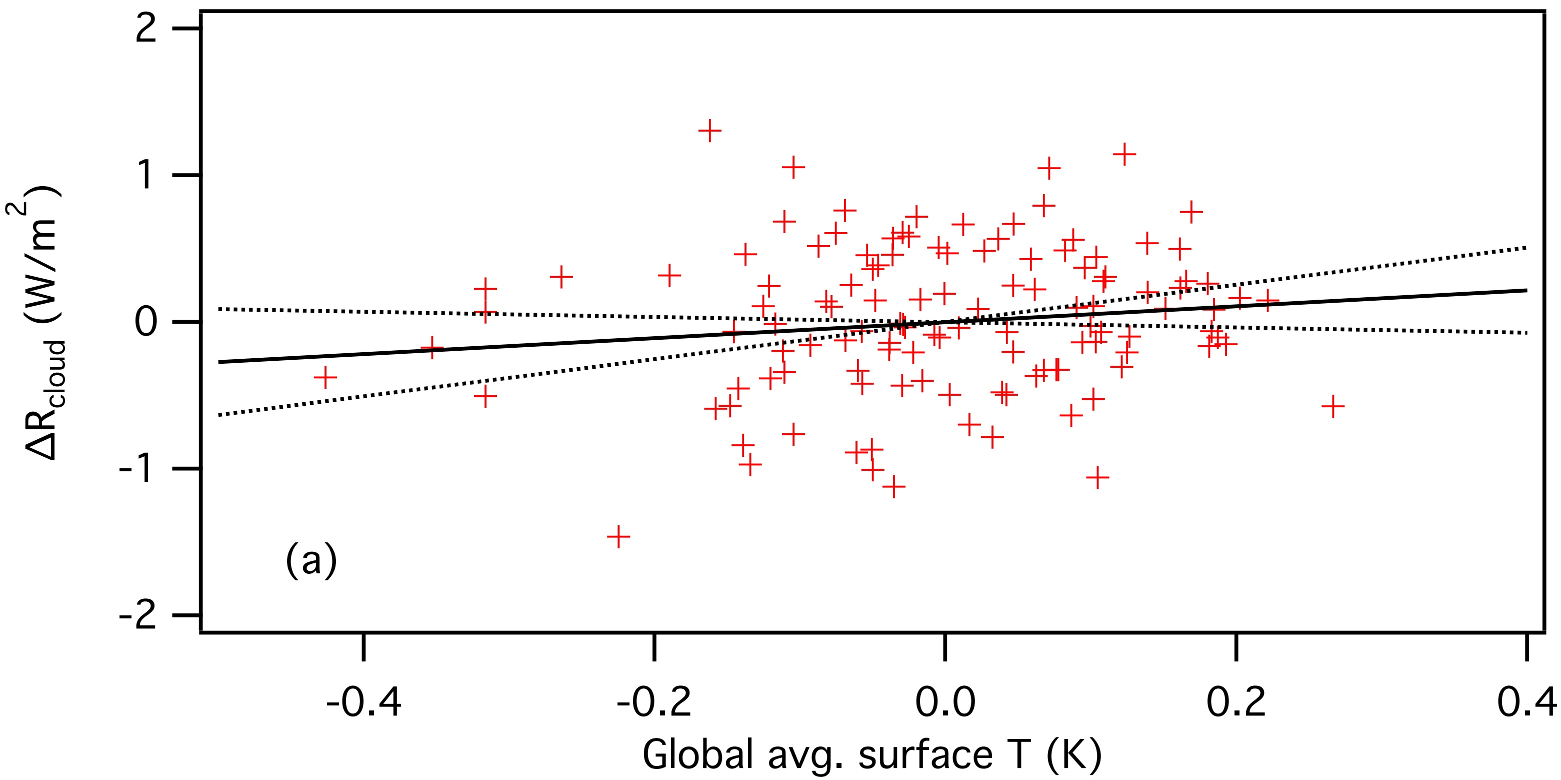


using ECMWF-interim

$\lambda_{cloud} = 0.54\pm0.72(2\sigma)$ W/m²/K (ECMWF); r^2=1.9%
$= 0.46\pm0.75(2\sigma)$ W/m²/K (MERRA); r^2=1.3%



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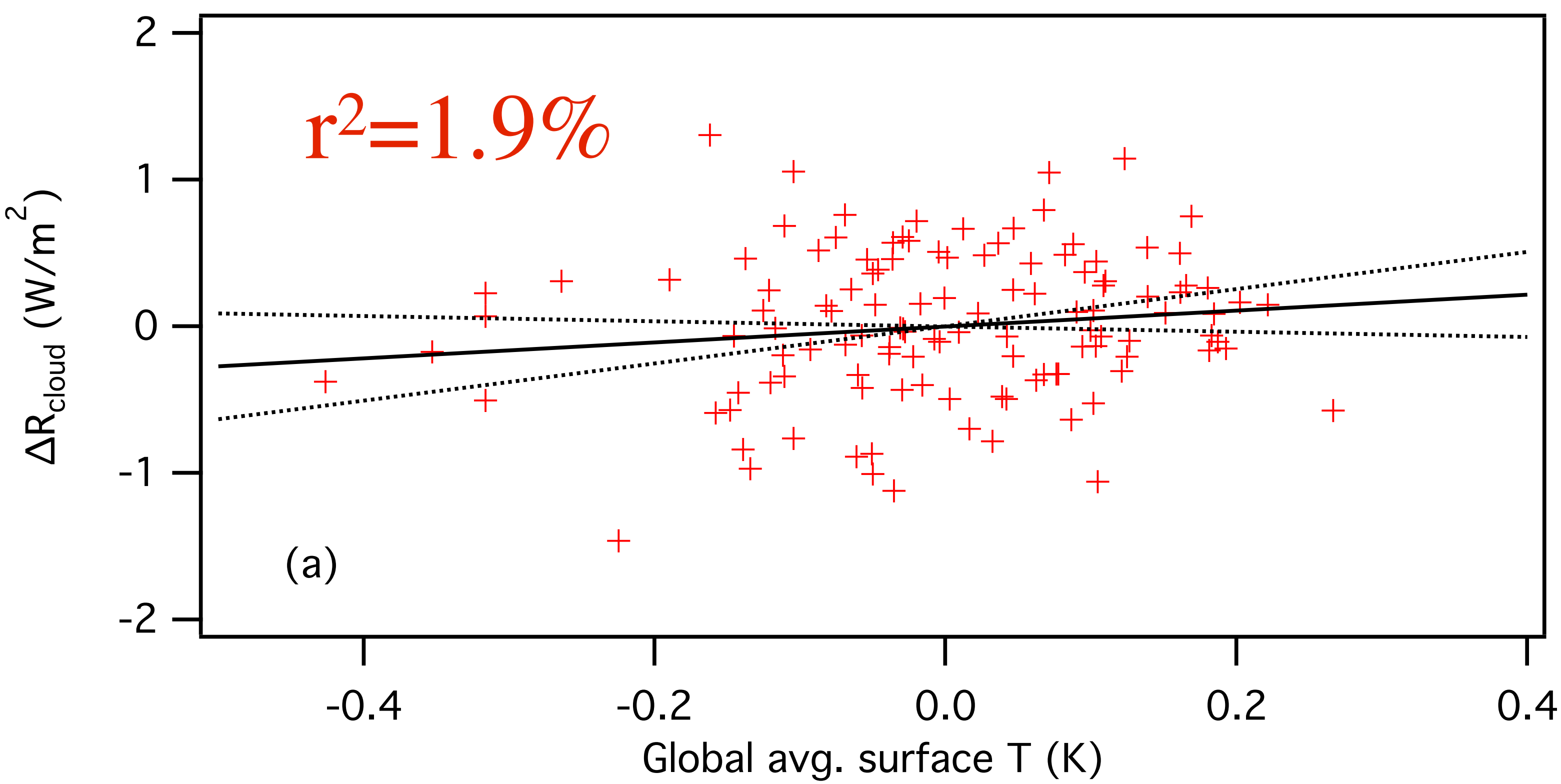

using ECMWF-interim

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- There is no evidence to support the existence a big negative cloud feedback (viz. Spencer, Lindzen and Choi)
- T_s explains little of the variance of ΔR_{cloud}
  - it will take many years to significantly reduce the uncertainty

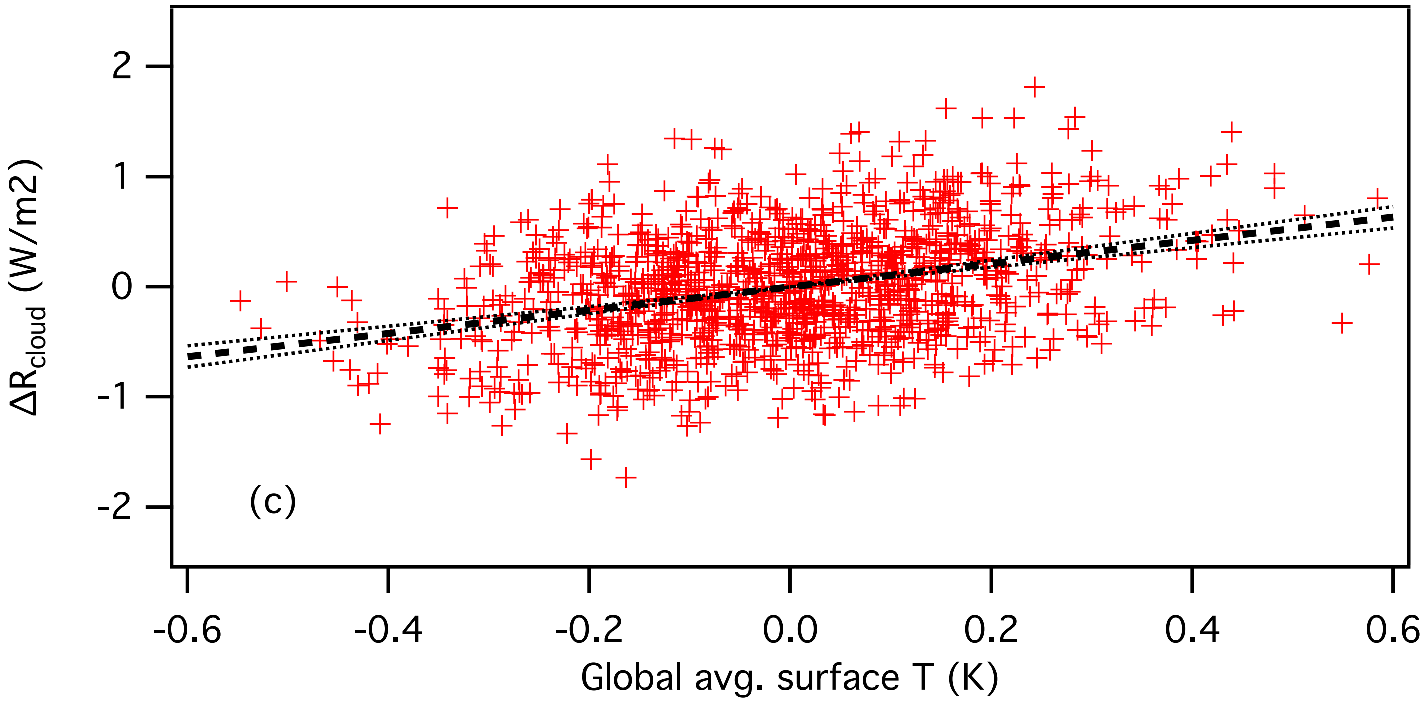
Do models get this right?

- Apply the same analysis to climate models
- Control runs
- Obtained from the PCMDI AR/4 archive

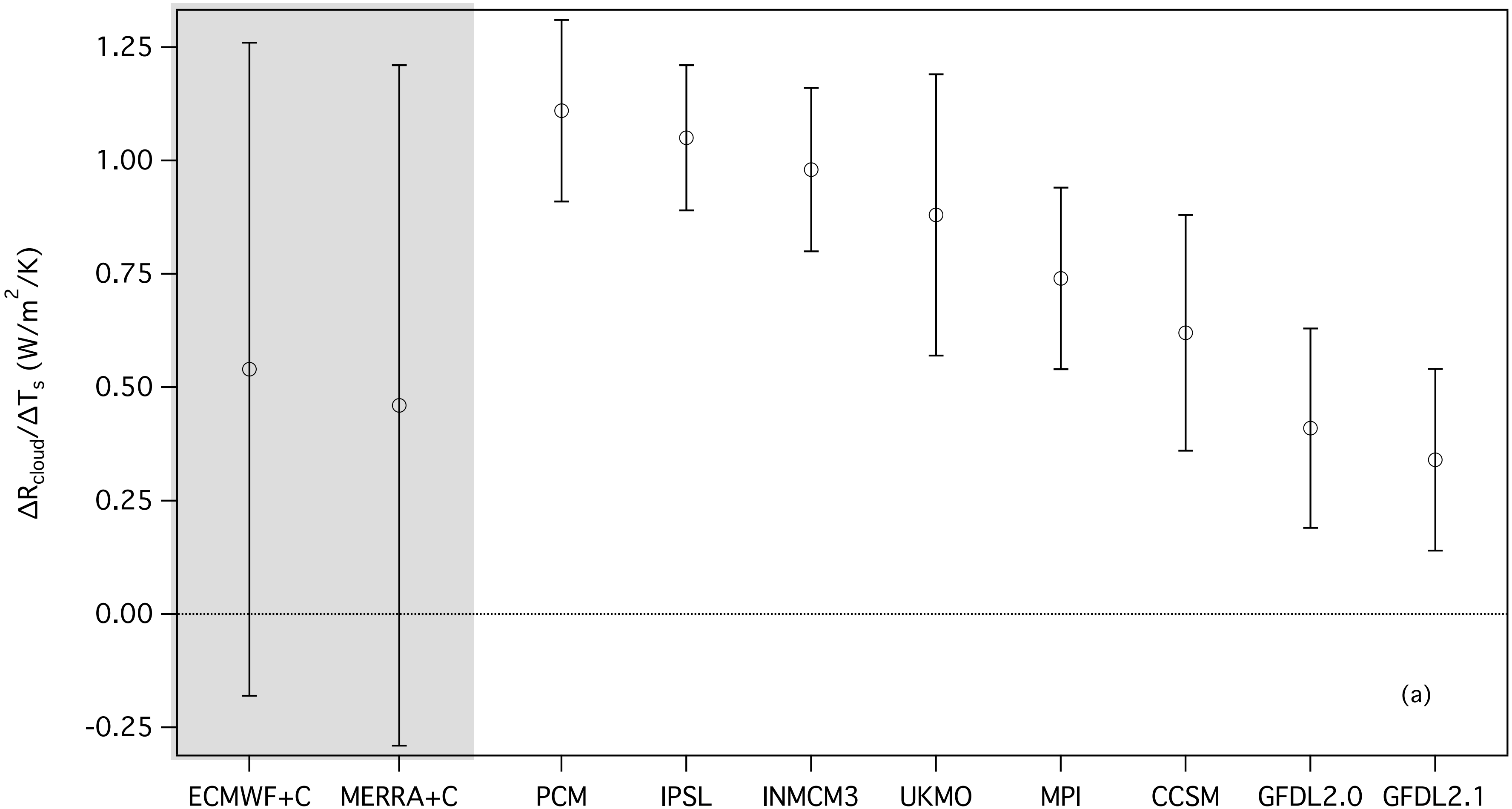
MPI ECHAM5

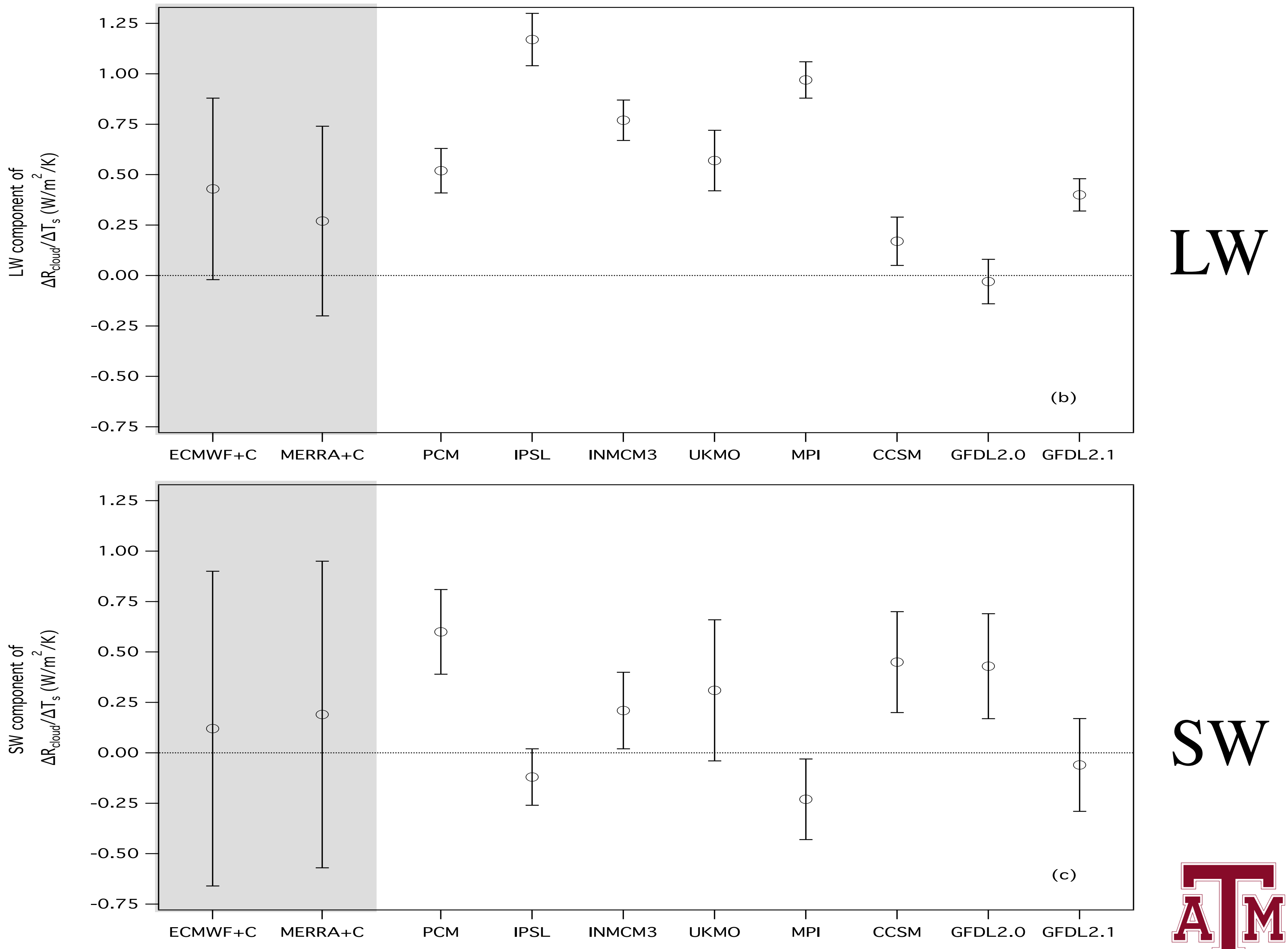
$\lambda_{cloud} = 0.74 \pm 0.20$ W/m^2/K
$r^2 = 4\%$

100 years of monthly averaged data



short-term cloud feedback intercomparison





LW component of $\Delta R_{cloud}/\Delta T_s$ (W/m^2/K)
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
(b)
ECMWF+C
MERRA+C
PCM
IPSL
INMCM3
UKMO
MPI
CCSM
GFDL2.0
GFDL2.1
LW
SW component of $\Delta R_{cloud}/\Delta T_s$ (W/m^2/K)
(c)
SW

Conclusions

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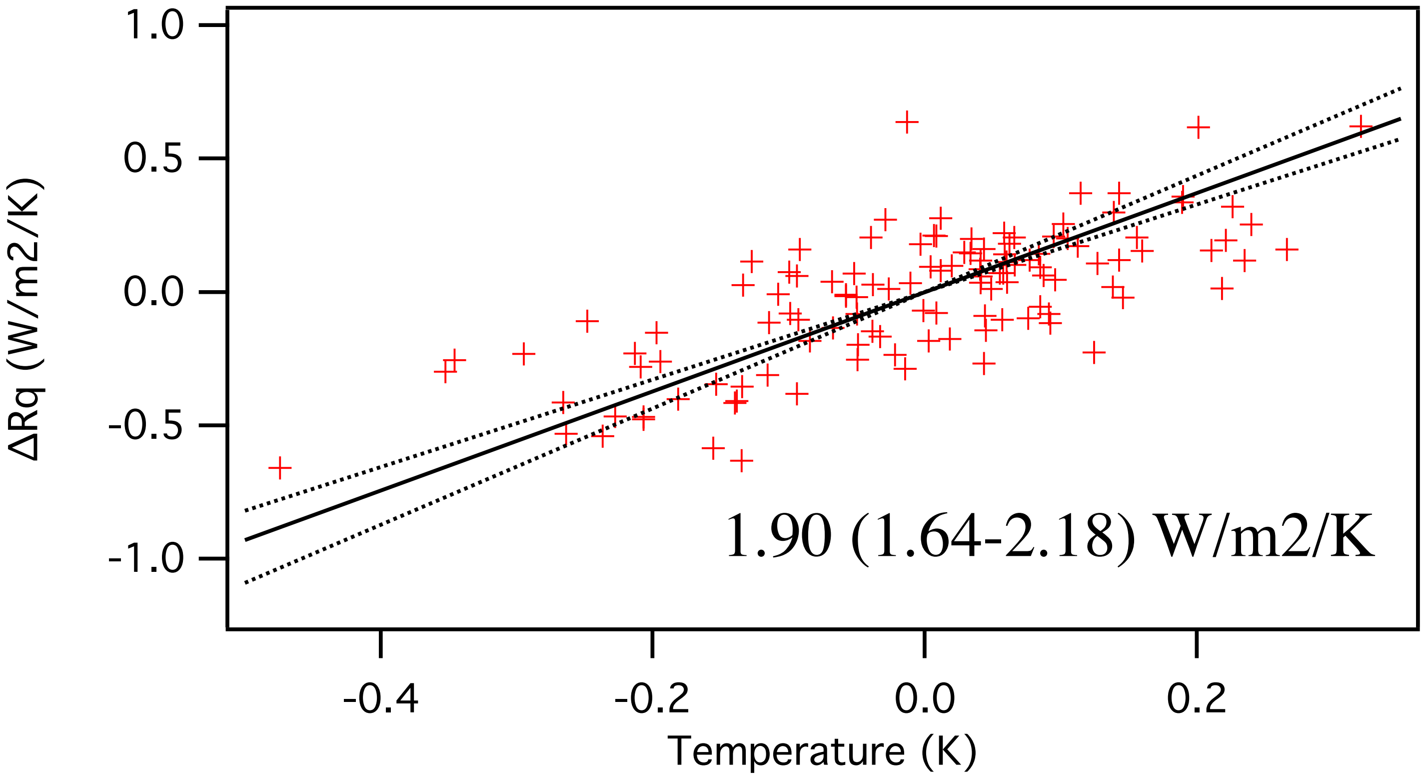
- I thank NASA grant NNX08AR27G to TAMU, the CERES, MERRA, and ECMWF groups, and the PCMDI archive

ECMWF-interim reanalysis
3/2000-2/2010



Tropical avg. T

Aerosols

aerosol climatology

aerosols

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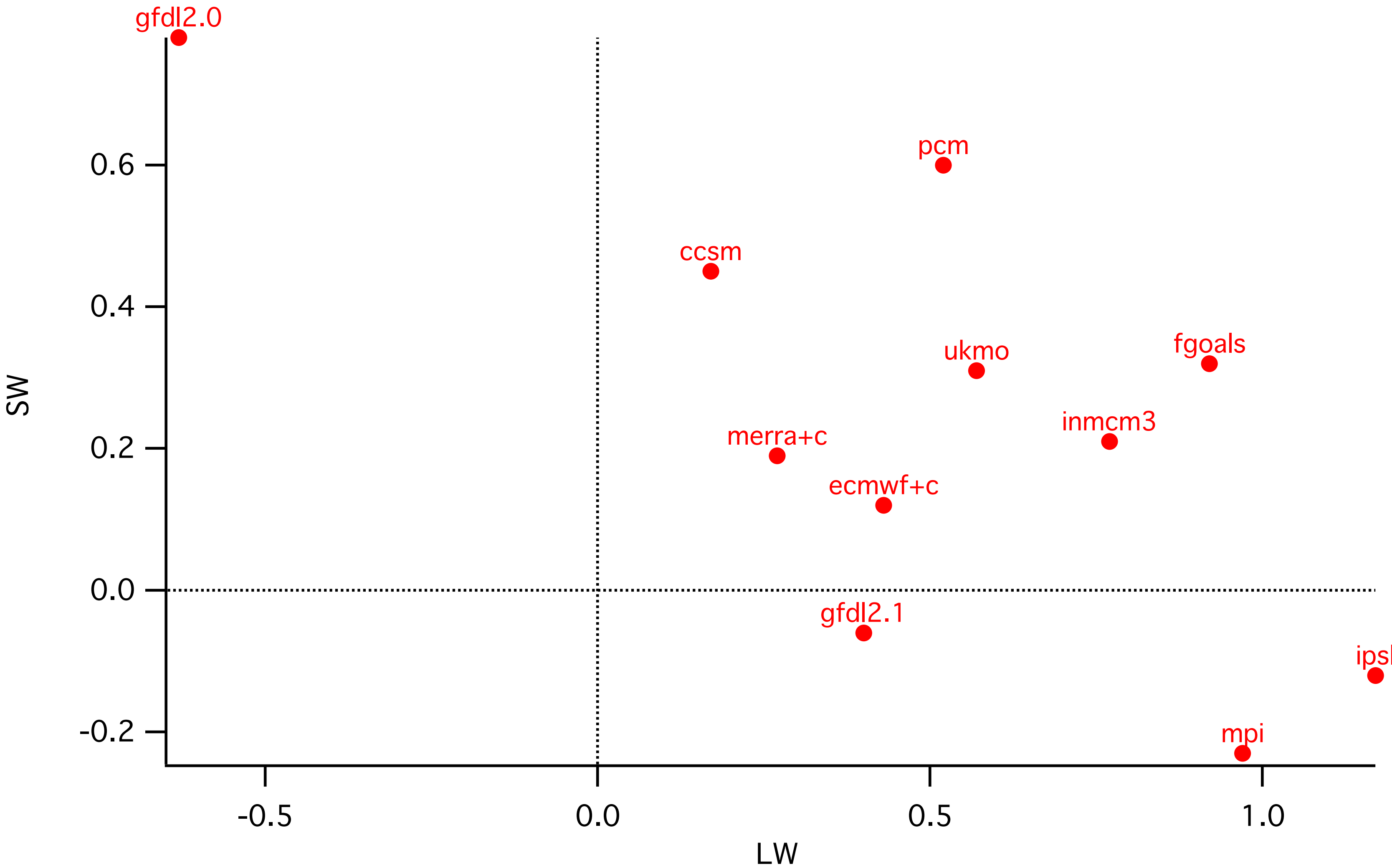
$$+ (K^0{}_a - K_a)da + (G^0 - G).$$

* difference goes into this term

* as long as it does not correlate w/ ΔT_s, inferred feedback should not be affected


gfdl2.0
pcm
ccsm
ukmo
fgoals
inmcm3
merra+c
ecmwf+c
gfdl2.1
ipsl
mpi
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SW
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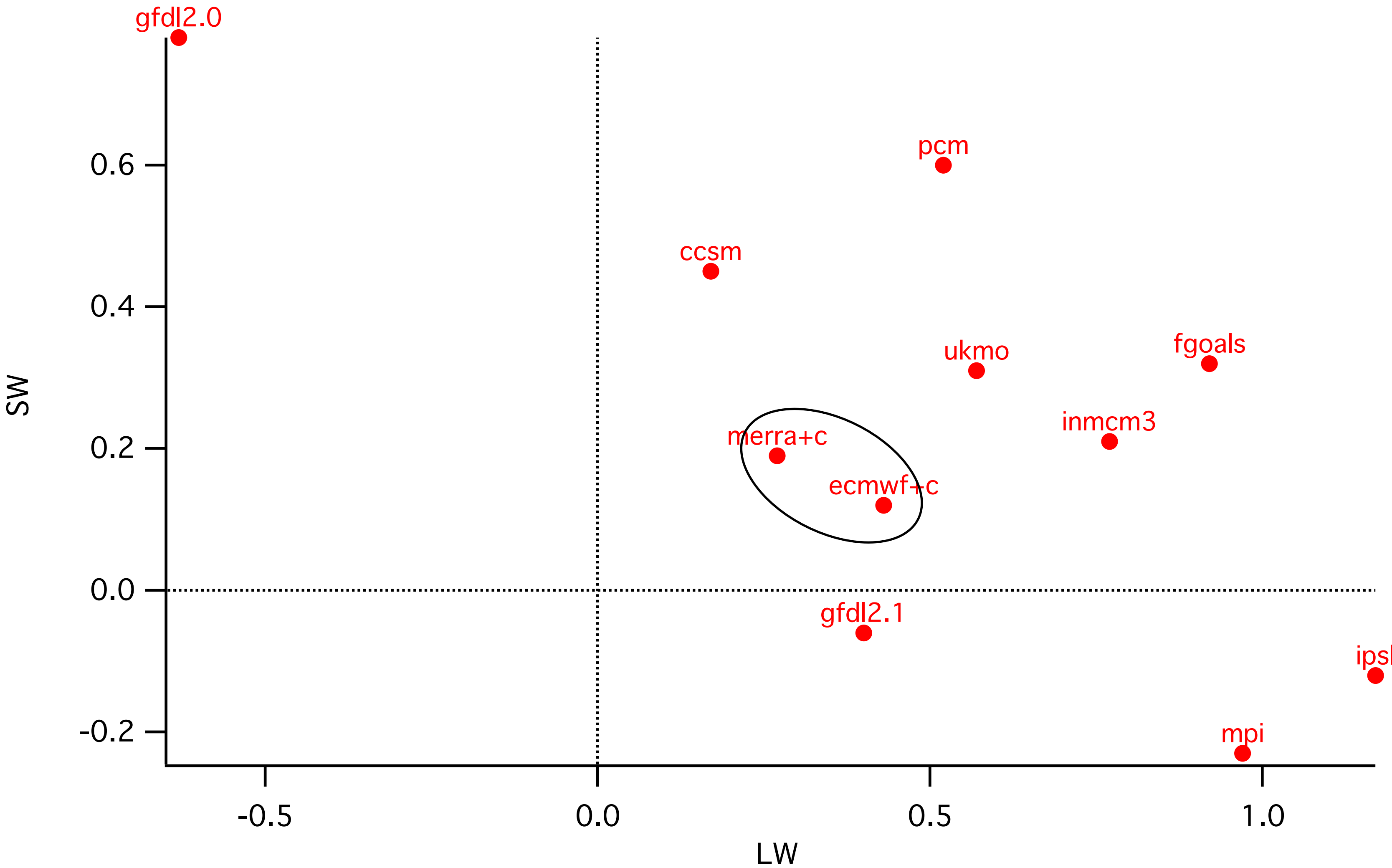
1.0
LW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merra+c
ecmwf+c
gfdl2.1
ipsl
mpi
0.6
0.4
0.2
0.0
-0.2
SW
-0.5
0.0
0.5
1.0
LW

Model	Total		Long wave		Short wave		Long-term cloud feedback	Climate sensitivity
	Cloud feedback	r^2	Cloud feedback	r^2	Cloud feedback	r^2		
FGOALS-g1.0	1.24±0.16	28%	0.92±0.08	48%	0.32±0.15	3%	N/A	2.3
PCM	1.11±0.20	10%	0.52±0.11	7%	0.60±0.21	3%	0.18	2.1
IPSL-CM4	1.05±0.16	12%	1.17±0.13	21%	-0.12±0.14	0.2%	1.06	4.4
INM-CM3.0	0.98±0.18	9%	0.77±0.10	15%	0.21±0.19	0.4%	0.35	2.1
UKMO-HadCM3	0.88±0.31	5%	0.57±0.15	9%	0.31±0.35	0.5%	1.08	3.3
ECHAM/MPI-OM	0.74±0.20	4%	0.97±0.09	27%	-0.23±0.20	0.4%	1.18	3.4
CCSM3	0.62±0.26	2%	0.17±0.12	0.9%	0.45±0.25	1%	0.14	2.7
GFDL-CM2.1	0.34±0.20	0.9%	0.40±0.08	8%	-0.06±0.23	0%	0.81	3.4
GFDL-CM2.0	0.15±0.20	0.2%	-0.63±0.10	11%	0.78±0.21	4%	0.67	2.9
ECMWF-CERES	0.54±0.72	1.9%	0.43±0.45	3.0%	0.12±0.78	0.1%	N/A	N/A
MERRA-CERES	0.46±0.75	1.3%	0.27±0.47	1.2%	0.19±0.76	0.2%	N/A	N/A

Have we measured a feedback?

- It makes sense if one thinks of cause and effect
- This is how feedbacks are traditionally defined
- The comparison with models is apples-to-apples

An analysis of the dependence of clear-sky top-of-atmosphere outgoing longwave radiation on atmospheric temperature and water vapor

A. E. Dessler,[1] P. Yang,[1] J. Lee,[1] J. Solbrig,[1] Z. Zhang,[1] and K. Minschwaner[2]

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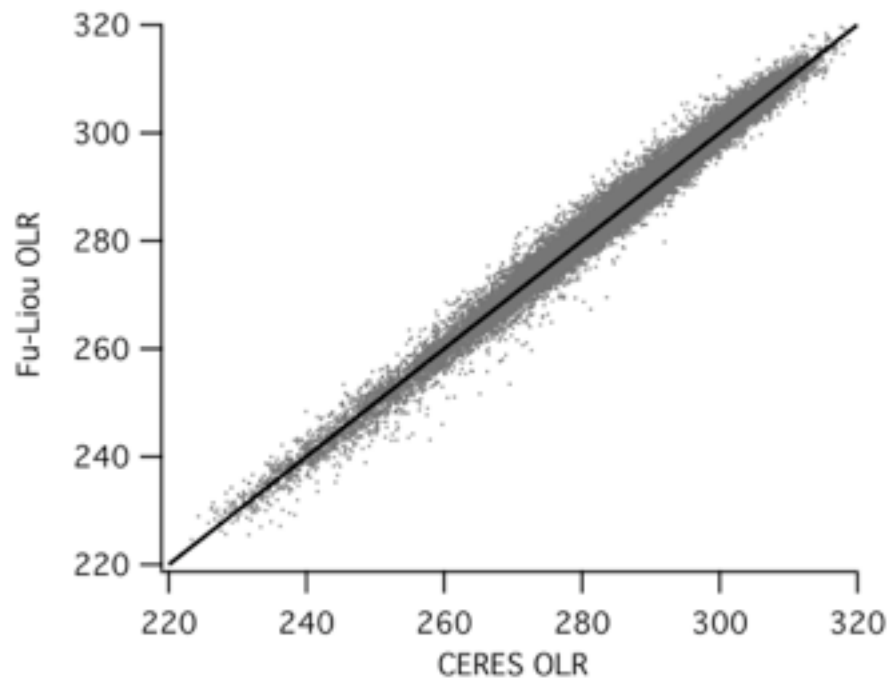
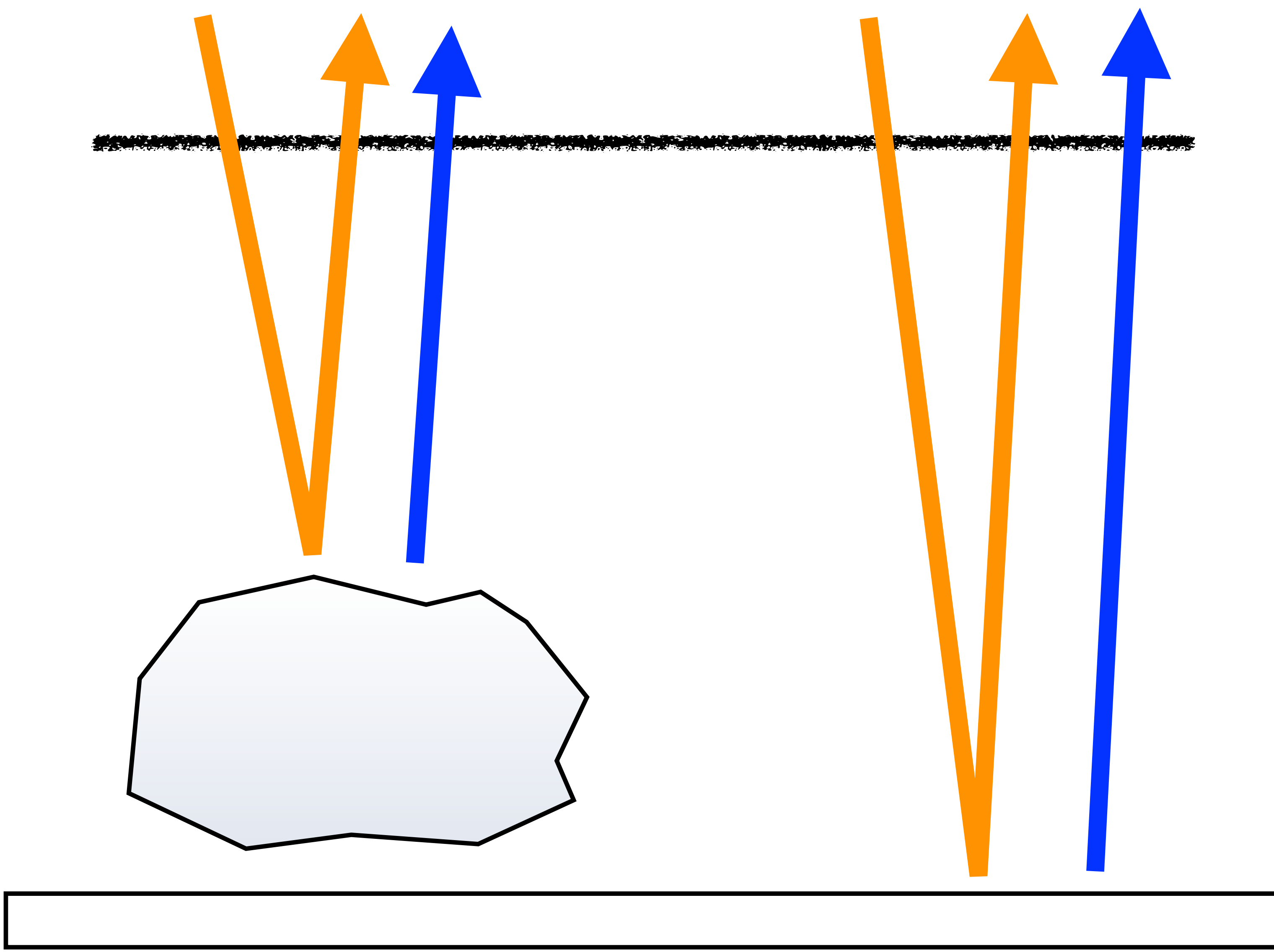


Figure 1. Scatterplot of 134,862 measured values of OLR against OLR calculated by the Fu-Liou model, both in units of W/m^2. The solid line is the one-to-one line.

$$CRF = R_{all\text{-}sky} - R_{clear\text{-}sky}$$

$$CRF = 0$$



$$CRF = R_{all\text{-}sky} - R_{clear\text{-}sky}$$

$$CRF \neq 0$$